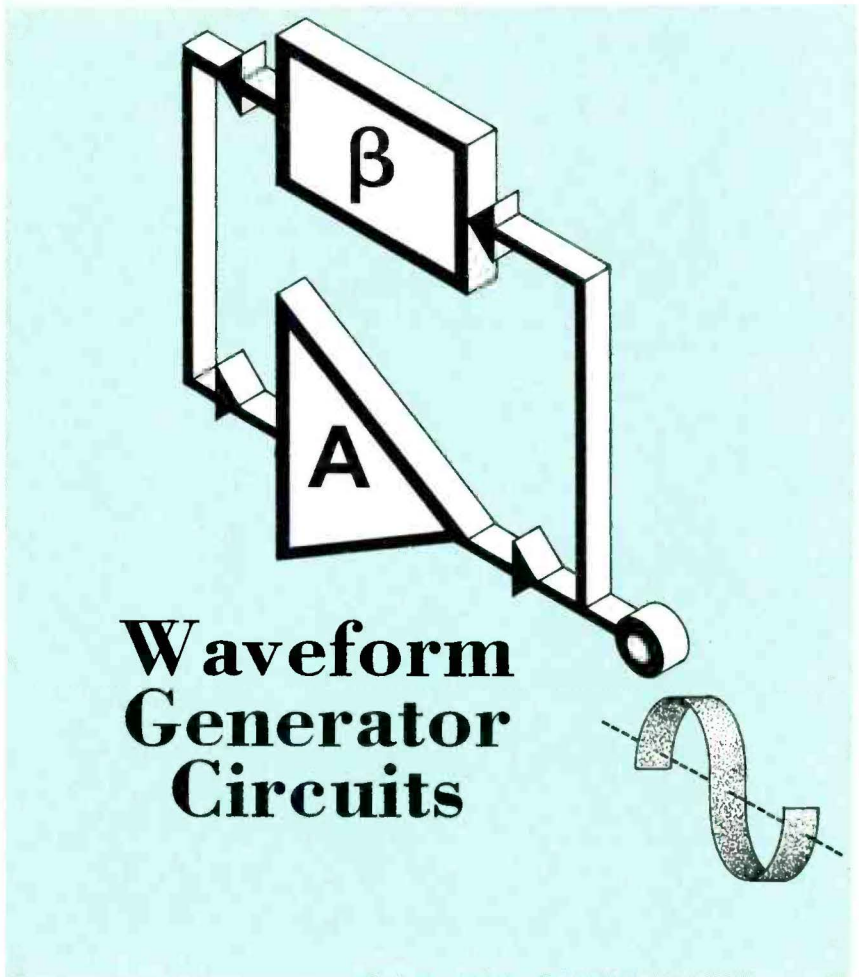

Learn about Wien-bridge and Twin-T oscillator circuits and put them to work in your circuit designs.

RAY MARSTON

CIRCUITS THAT ARE CAPABLE OF generating a variety of waveforms are important for test and analysis in electronics. The sinewave, the most useful waveform, can be generated by various resistive-capacitive (RC) or inductive capacitive (LC) oscillators. They can also be synthesised by integrated circuit waveform generators. This article focuses on two popular, low-frequency sinewave and square wave generators, the Wien-bridge and twin-T oscillators.

Oscillator fundamentals

An oscillator, as illustrated in block diagram Fig. 1, is basically an amplifier with positive feedback. The gain equation for an amplifier with positive feedback is:

$A_F = A/(1 + A\beta)$

Where:

A_F = gain with feedback

A = open-loop gain

β = feedback factor, $V_i/Vsbo$

Feedback is provided by the feedback or phase-shift network, as shown in Fig. 1. The output signal is fed back to the amplifier's input terminal through a phase-shift network, where it undergoes a 180° phase shift. The amplifier also causes a 180° phase shift. The two conditions for sustained oscillation are known as the *Barkhausen criteria*.

1. The phase shift in the circuit is zero.
2. The closed-loop gain, the product of Aβ, must be equal to or greater than one.

An input signal is not necessary to start oscillation—a transient is sufficient. The closed-loop gain should be greater than unity to ensure strong oscillations. However, if the gain is too high , the circuit will operate in a saturation condition, and the sinewave will be distorted.

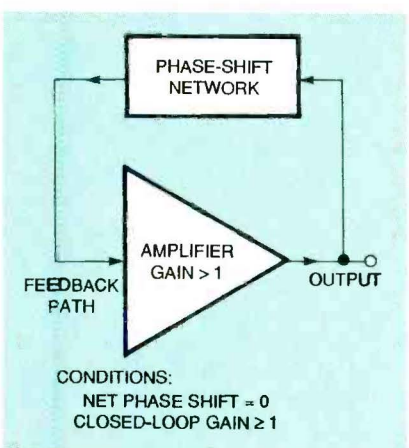

FIG. 1—CONDITIONS for oscillation based on an amplifier.

An oscillator's frequency-selective, phase-shift network consists of a combination of resistive and capacitive components (RC) or inductive and capacitive components (LC). A combination of inductive and capacitive components is called a *tuned circuit* or a *tank circuit*.

RC oscillators are preferred to LC oscillators at low frequencies because the size and weight of inductors at low frequencies makes the circuit too large and heavy. RC sinewave oscillators work best at frequencies from 10 Hz to about 150 kHz. This band includes the audio-frequency range of 20 Hz to 20 kHz. By contrast, LC networks work best at frequencies above 50 kHz. There is some overlap between these frequency ranges. The most common output impedances of audio oscillators are 75 ohms and 600 ohms.

Two popular low-frequency oscillators with RC phase-shift networks commonly used today are the Wien-bridge and twin-T oscillators.

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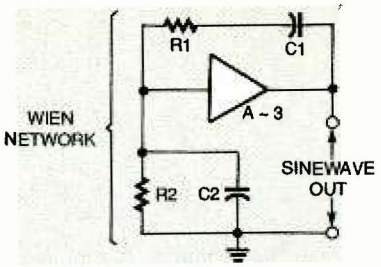

FIG. 2—BASIC WIEN-BRIDGE oscillator for producing sinewaves.

whose balance is achieved at a single frequency. The oscillator produces a relatively pure sinewave at a very stable frequency.

Figure 2 is a simplified diagram of a Wien-bridge oscillator showing an amplifier with a Wien-bridge, RC frequency-selective network. The Wien network consists of resistor and capacitor pairs R1 and C1 in series and R2 and C2 in parallel.

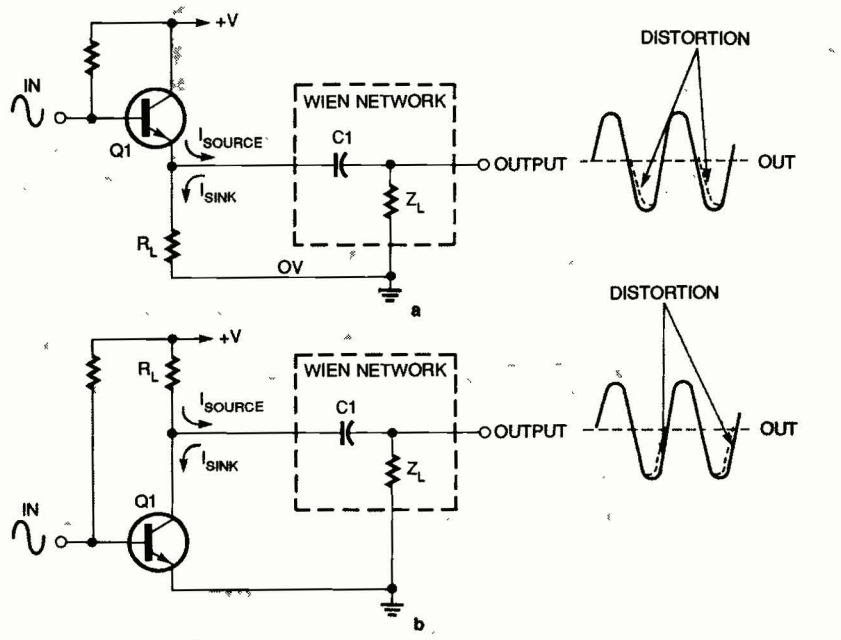

FIG. 3—WAVEFORM DISTORTION from an emitter-follower amplifier (a), and common-emitter amplifier (b), if the value of the load resistor exceeds the load impedance.

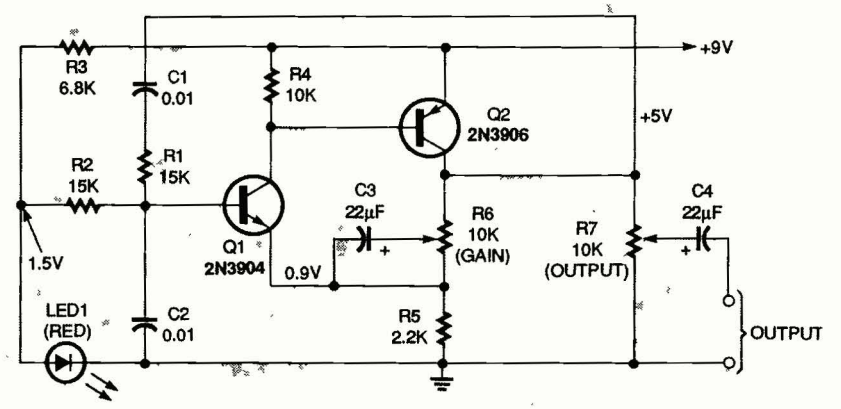

FIG. 4— THIS WIEN-BRIDGE OSCILLATOR generates variable-amplitude, 1-kHz sinewaves.

Wien-bridge oscillator

The Wien-bridge oscillator is essentially a feedback amplifier that includes a Wien bridge as its phase-shift network. The Wien bridge is an AC bridge whose balance is achieved at a single frequency. The oscillator produces a relatively pure sinewave at a very stable frequency.

Figure 2 is a simplified diagram of a Wien-bridge oscillator showing an amplifier with a Wien-bridge, RC frequency-selective network. The Wien network consists of resistor and capacitor pairs R1 and C1 in series and R2 and C2 in parallel. Here C1 = C2 = C, and R1 = R2 = R. The main characteristic of the Wien network is that the phase relation between its output and input signals can vary from −90° to +90°, and it is precisely zero at the center frequency $f_0 = 1/(2\pi \times RC)$.

At this frequency, the network has a voltage gain of 0.33. The Wien network in Fig. 2 is connected between the output and input of a noninverting amplifier with a voltage gain of 3. Consequently, the circuit has a zero overall phase shift and a unity loop gain at the center frequency. These satisfy the Barkhausen criteria for oscillation.

A practical Wien network is unlikely to be precisely symmetrical because of the tolerances of its components, so its gain might deviate widely from the ideal 0.33 value. To compensate for this variation and permit the oscillator's loop gain to be set at unity, the amplifier's gain must be variable between about 3 and 5

Moreover, the loop gain must initially be slightly greater than one to initiate oscillation. Then it must be reduced, either manually or automatically, to a value of one necessary to produce low-distortion sinewaves.

If the amplifier's output stage is a simple emitter follower, it might not be a low-distortion drive for the Wien-bridge network. This can be seen in Fig. 3-a, a schematic for a sinewave-driven NPN transistor emitter-follower Q1 driving the input of a Wien-bridge network. The network is represented by capacitor C1 and complex load Z_L.

On positive-going half-cycles, the forward currents of C1 and Z_L are sourced (supplied) by transistor Q1, but on negative-going half-cycles, their reverse currents are sunk (absorbed) by R_L. If R_L is large relative to Z_L, the reverse currents of C1 and Z_L might be too low to permit the Z_L voltage to follow the negative-going half cycles. If this occurs, the waveforms will be distorted, as shown in Fig. 3-a.

Similar distortion can occur if the amplifier's output stage is an NPN common-emitter amplifier, as shown in Fig. 3-b. Here, the distortion that occurs if R_L is large relative to Z_L appears on the rising edge of the output waveform because the C1-Z_L source currents flow through

Continued on page 82

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continued from page 36

R_L, and the sinking current flows through transistor Q1. These distortion problems do not occur with a complementary emitter follower because that circuit can source or sink high output currents with equal ease.

Transistor oscillators

Figure 4 is a schematic for a Wien-bridge oscillator based on two transistors. It will generate 1-kHz sinewaves. The oscillator draws 1.8 milliamperes from a 9-volt supply, and has an output amplitude that can be widely varied with output potentiomer R7 up to 6 volts peak-to-peak. The circuit operates as follows:

Transistors Q1 and Q2 are a pair of direct-coupled complementary feedback, common-emitter amplifiers. They present a very high input impedance to the base of Q1 and a low output impedance from Q2's collector. They also present a noninverted DC-voltage gain of 5.5, obtained from the resistor relationship of R6 + R5/R5. (Substituting the resistor values shown in Fig. 4 of 10K + 2.2K/2.2K ohms gives a gain of 5.5.)

Transistors Q1 and Q2 also provide an AC voltage gain that is variable from 1.0 to 5.5 with potentiometer R6. Transistor Q2's collector load impedance (determined by R5, R6, and R7 is approximately 5 kilohms.

Red LED lamp LED1 conducts through R3 to generate a stable, low-impedance 1.5-volt bias source. That bias is fed to the base of transistor Q1 through R2. This biases Q2's output to a quiescent value of +5 volts. The Wien network (formed by R1-C1 and R2-C2 and connected between Q2's output and Q1's input) has an active impedance of about 15 kilohms and is driven by Q2's output. Potentiometer R7 can vary the oscillator's output amplitude widely.

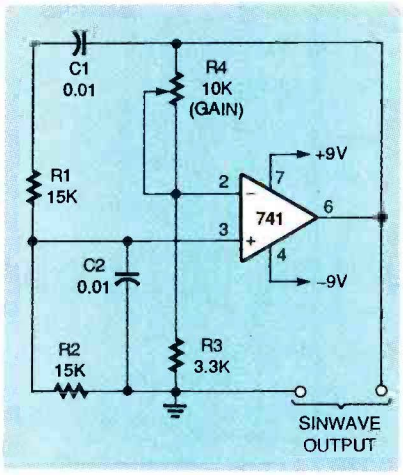

FIG. 6—A WIEN-BRIDGE oscillator based on an operational amplifier.

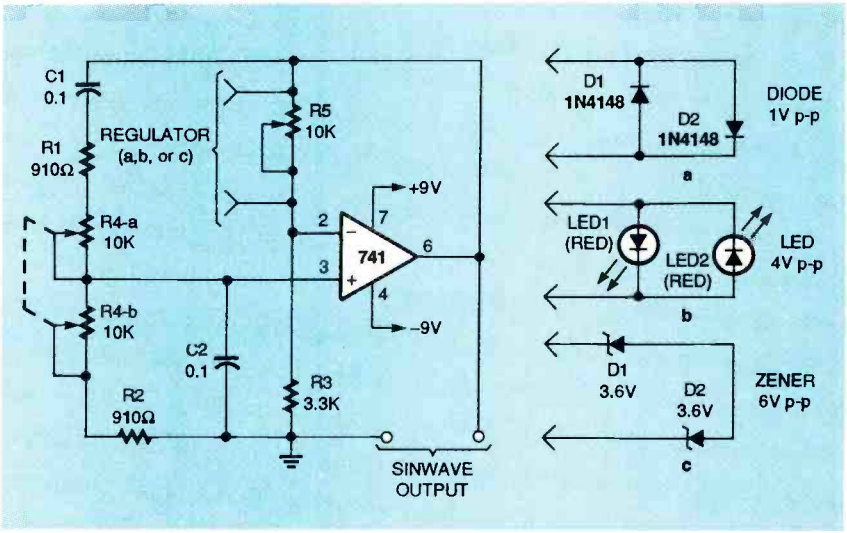

FIG. 7—AMPLITUDE OF SINEWAVES can be varied by a choice of three different voltage regulators in the 150-Hz to 1.5-kHz frequency range Wien-bridge oscillator.

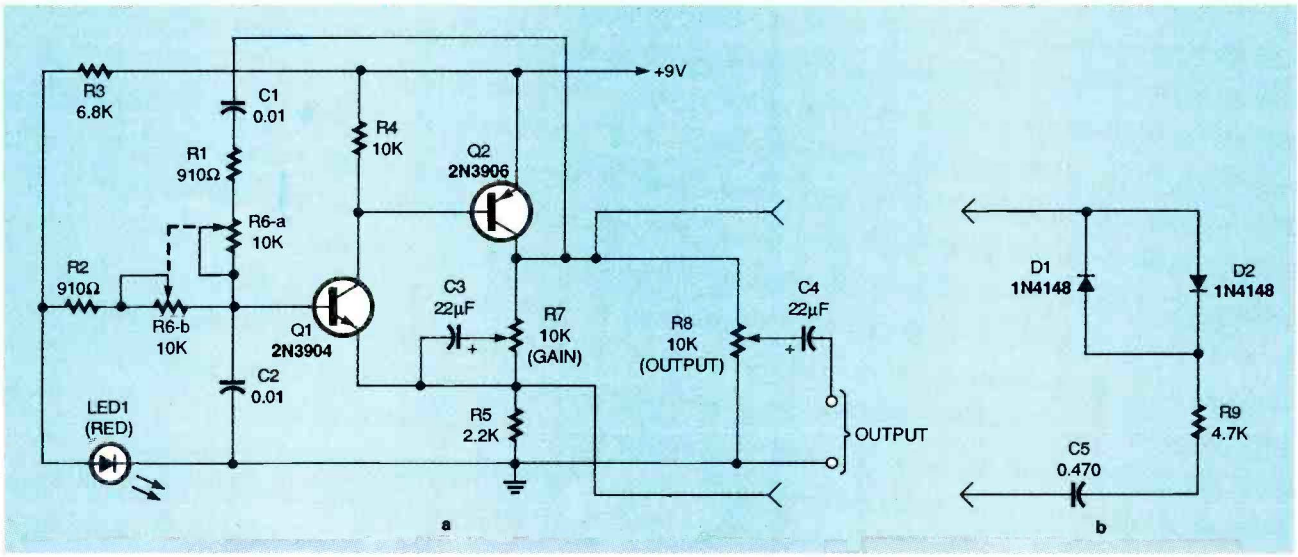

FIG. 5—THIS WIEN-BRIDGE OSCILLATOR will demonstrate its ability to generate variable frequencies between 1.5 and 15 kHz.

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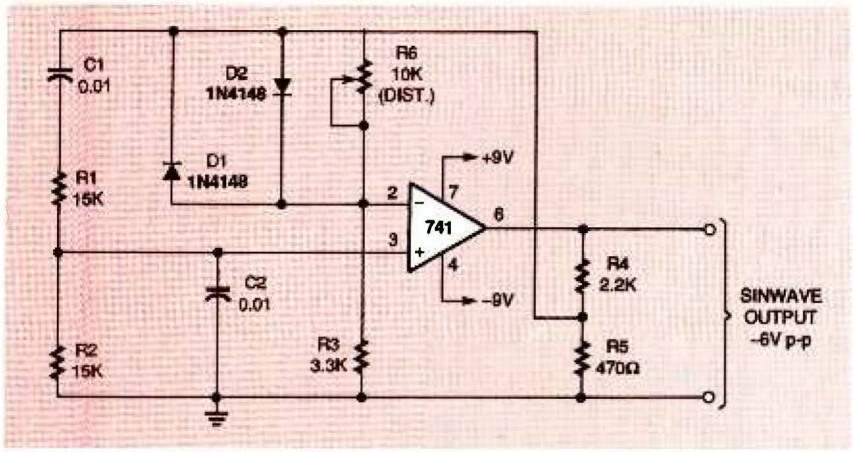

FIG. 8—A 1-kHz WIEN-BRIDGE OSCILLATOR with an amplified-diode regulator.

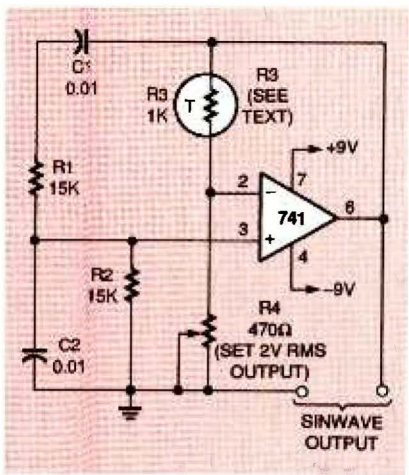

FIG. 9—A 1-kHz WIEN-BRIDGE OSCILLATOR with an NTC thermistor regulator.

To organize the oscillator in the Fig. 4 circuit, connect its output to an oscilloscope and adjust potentiometer R6 so that a stable, clean waveform is generated on the oscilloscopes's screen. In this condition, oscillation amplitude is limited only by the onset of positive-peak clipping as the amplifier encounters saturation.

This clipping occurs at a peak-to-peak amplitude of about 6 volts. The clipping is a kind of distortion-generated automatic gain control (AGC) that reduces the oscillator's loop gain below the critical unity level as the waveform's amplitude reaches a specific peak value. If potentiometer R6 is carefully adjusted, this clipping can be reduced to an almost imperceptible level. The result will be high-quality sinewaves with less than 0.5% total harmonic distortion (THD).

The Wien-bridge oscillator circuit in Fig. 4 is versatile and inexpensive in fixed- and switched-frequency applications where a single-ended power supply is required. However, the values of resistors R1 and R2 must not be less than 5 kilohms. The R1-R2 and C1-C2 values can be varied over a wide range to give alternative operating frequencies. Moreover, small frequency changes can be obtained by altering the value of either R1 or R2.

Figure 5 is a schematic for a Wien-bridge oscillator, a modification of the Fig. 4 schematic. The oscillation frequency of the circuit is fully variable from 1.5 kHz to 15 kHz with dual potentiometer R6. The circuit can be both a practical sinewave generator and a Wien-bridge oscillator demonstrator. The Wien bridge is made up of C1-R1-R6-a and C2-R2-R6-b.

To demonstrate the Wien-bridge oscillator with this circuit, build it as shown in Fig. 5-a, and connect its output to an oscilloscope. Set output potentiometer R8 for maximum output, and set dual potentiometer R6 to its maximum resistance value to provide the lowest frequency. Then carefully adjust potentiometer R7 so that clean, stable waveforms appear on the oscilloscope. When set up this way, the Wien network presents a high impedance and is easily driven by transistor Q2. As a result, oscillation amplitude is limited only by the onset of positive-peak clipping at an amplitude of about 6 volts, peak-to-peak, as described earlier.

Progessively increase the operating frequency by reducing the resistance of R6 while retrimming R7 as necessary to maintain oscillation, until the maximum frequency is obtained. Under this condition, the waveform's peak-to-peak amplitude drops to about 3 volts, and slight distortion is visible on the falling halves of the waveform. This is caused by transistor Q2 losing its ability to drive the Wien network cleanly as its impedance drops below a few kilohms. The result is a form of amplitude-limiting, distortion-generated AGC.

This distortion can be overcome, at the expense of a large increase in the circuit's quiescent current, by inserting a 1.5-kilohm resistor between transistor Q2's collector and ground. This increases Q2's output drive capability. However, with this modification, the waveform's amplitude is again limited by clipping at about 6 volts, peak-to-peak.

To finish setting up the network as a demonstration unit, remove the 1.5-kilohm resistor from Q2's collector, and connect the network formed by diodes D1 and D2, resistor R6 and capacitor C5, as shown in Fig. 5-b across potentiometer R7, at the two jacks.

Vary the wiper of potentiometer R6 across the whole frequency band, and trim potentiometer R7 to find a position where you obtain a clean sinewave with an amplitude of about 1.2 volts peak-to-peak, at all settings of R6. Resistor R6 and the two diodes, D1 and D2, introduce a form of gain control. At the start of each half-cycle, the circuit's loop gain is greater than one, so oscillation starts. However, as soon as the waveform amplitude approaches a peak value of about 600 millivolts, either D1 or D2 will conduct, shunting 4.7-kilohm resistor R9 across R7, thus reducing the loop gain to unity.

This is a gentle form of limiting that causes less than 1% THD. The version of Fig. 5 circuit with the D1, D2, R9, and C5 network plugged in becomes an

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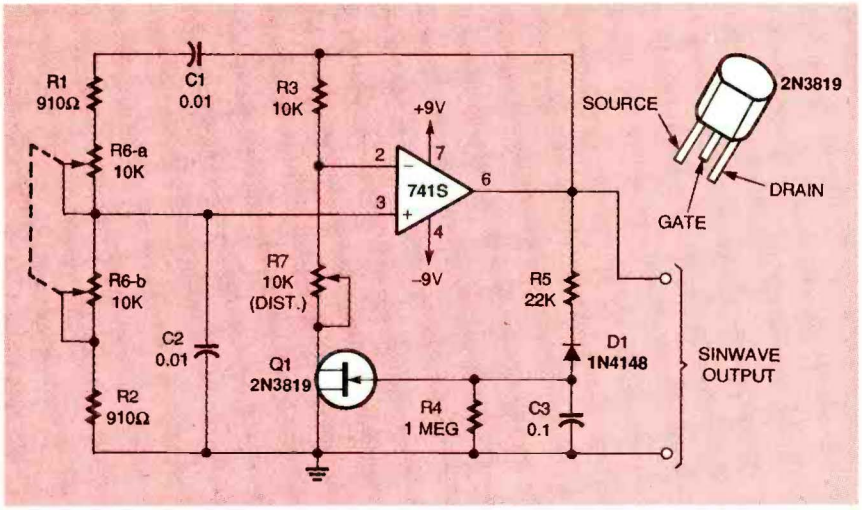

FIG. 10—A JFET-REGULATED 1.5- to 15-kHz Wien-bridge oscillator.

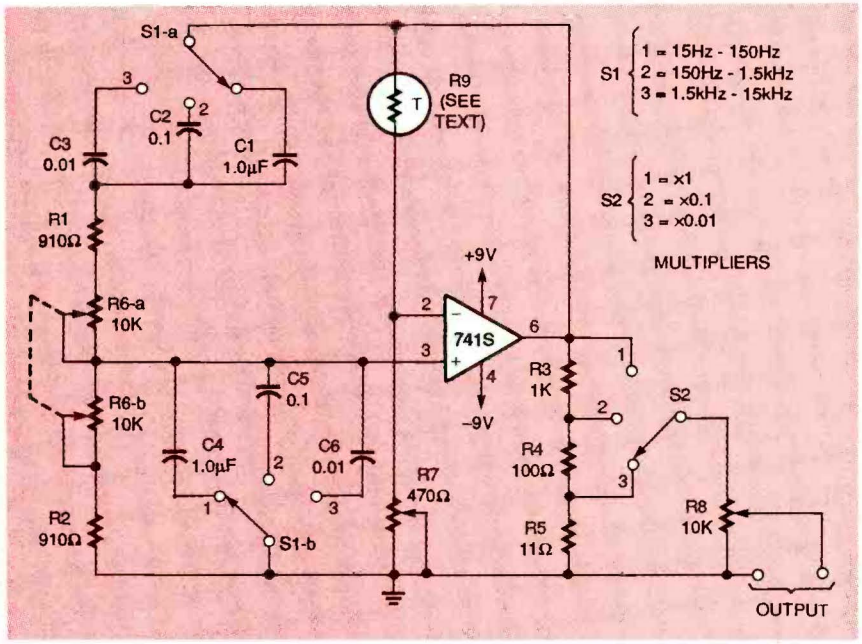

FIG. 11—A THREE-DECADE (15 Hz to 15 kHz) Wien-bridge oscillator.

inexpensive but effective variable-frequency sinewave generator whose frequency range can be changed by substituting different values for capacitor C1 and C2.

Oscillators with op-amps

Standard integrated-circuit operational amplifiers offer high voltage gain, high input impedance, and low output impedance. They are excellent amplifiers for Wien-bridge oscillators. Figure 6 is a schematic for a simple 1-kHz oscillator. Resistor-capacitor pairs R1-C1 and R2-C2 form the Wien-bridge network. Trimmer potentiometer R4 and resistor R3 control the operational amplifier's closed-loop gain.

The circuit oscillates when R4 is adjusted, but its waveform amplitude is limited only by the onset of peak clipping as the op-amp encounters saturation. If R4 is adjusted carefully, clipping can be reduced to an insignificant level, so that the output sinewaves are clean. However, this technique is useful only in fixed-frequency applications. Where variable frequency is desired, some form of gain control must be provided so that there will be amplitude limiting with minimal distortion.

Figure 7 shows three ways to regulate waveform amplitude with diodes providing the distortion-generated AGC, as described earlier. The simple plug-in, back-to-back 1N4148 diode regulator, shown in 7-b, is the least expensive solution. However, its output is limited to 1 volt, peak-to-peak, for low-distortion levels.

The light-emitting diode plug-in regulator (Fig. 7-c) gives a 4-volt peak-to-peak output and the series Zener diode plug-in regulator (Fig. 7-d) gives a peak to peak output of 6 volts. With any of these plug in regulators in position, adjust trimmer potentiometer R5 for the minimum setting that gives sustained oscillation across the whole frequency band. If the Wien bridge components are well matched, THD might be less than 0.5%.

Figure 8 shows a diode-regulated Wien-bridge oscillator that is well suited for fixed-frequency applications. Here, both the Wien-bridge and regulator-feedback loop are taken from the output junction of resistors R4 and R5. This is an alternative to taking it directly from the output of the operational amplifier. This simple modification effectively amplifies the diode regulation voltage by a factor determined by the ratio of the value of (R4 + R5)/R5. In the Fig. 8 circuit, the sinewave output is about 6 volts, peak-to-peak. If trimmer R6 is adjusted carefully, THD levels of 0.1% can be obtained.

Linear AGC circuits

The Wien-bridge oscillators shown in Figs. 6, 7, and 8 rely on distortion-generated AGC to control waveform amplitude. Those circuits can maintain a constant and jitter-free amplitude as the frequency is increased and decreased across the available band.

There is an alternative based on automatic linear gain control. Oscillators with this feature usually generate negligible distortion. However, they suffer from amplitude "bounce" when the frequency settings are shifted up and down the available band. The AGC system hunts for the correct gain value. Fig-

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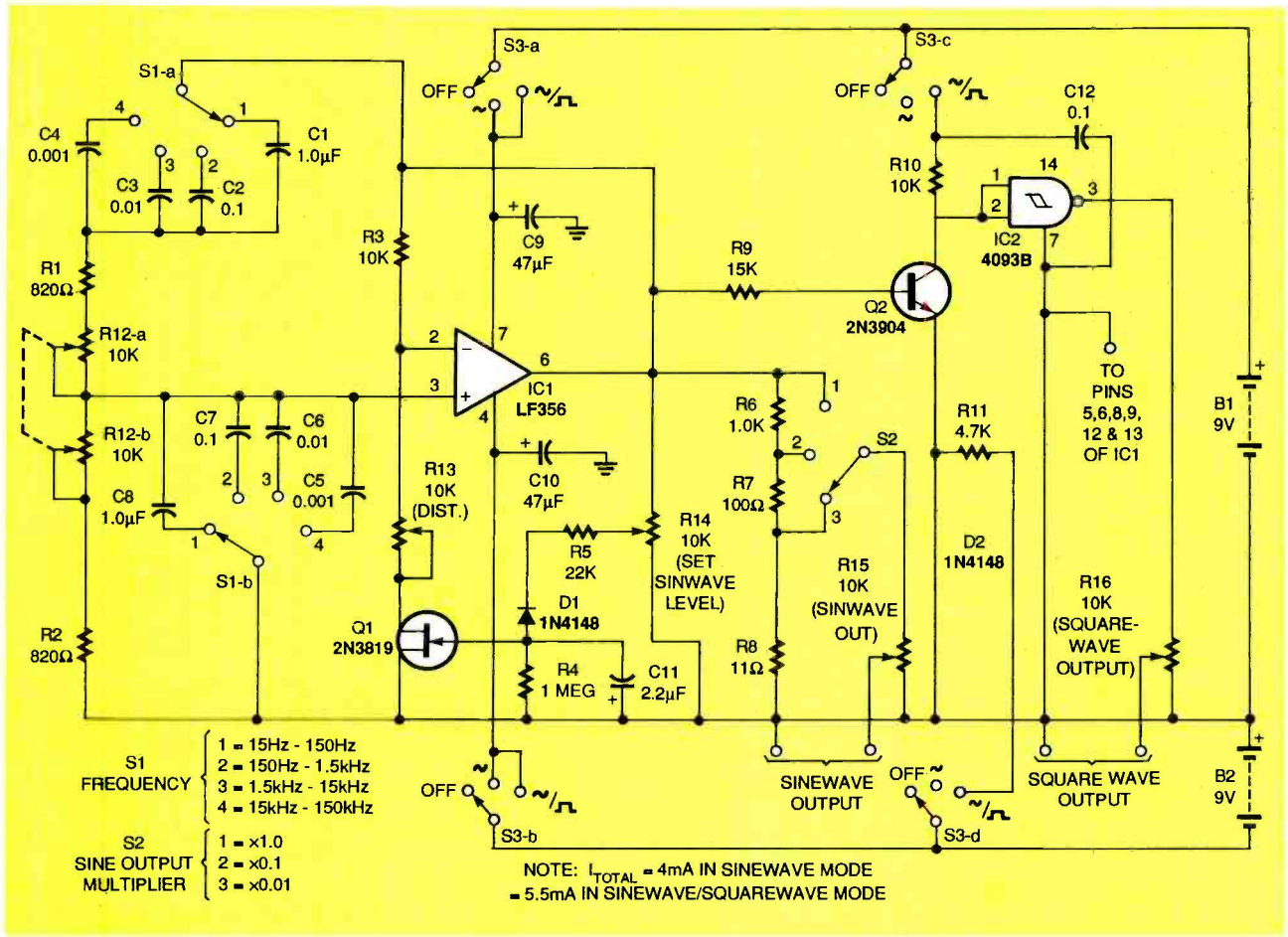

FIG. 12—THIS SINE/SQUAREWAVE generator covers the 15-Hz to 150-kHz band.

ures 9, 10, and 11 show three circuit schematics that contain linear AGC circuits.

Figure 9 is the schematic for a 1-kHz oscillator circuit whose output amplitude is stabilized by a negative temperature coefficient (NTC) thermistor. It is shown here as R3, a resistor symbol in a circle containing the letter T. The resistance of an NTC thermistor decreases as temperature increases. Typical resistance values for NTC thermistors devices range from 200 ohms to 50 kilohms. Thermistor R3 in series with trimmer potentiometer R4 becomes a gain-determining feedback network. The value of R3 is 1 kilohm.

Thermistor R3 is heated by the output signal's average power. At the desired amplitude, R3 has a resistance value double that of the 470-ohm trimmer potentiometer R4, thus giving the circuit an overall gain of unity. If the output amplitude starts to rise, R3's temperature rises and its resistance falls. This response reduces the gain and restores the original output level. The reverse action occurs if the output starts to fall, and the original output level is again restored. This oscillator generates negligible distortion.

Figure 10 is the schematic for an alternative circuit that consumes only a few milliamperes. In this circuit, JFET Q1 serves as a variable resistance that is voltage-controlled by the oscillator's negative peak amplitude. This is detected by the series network of resistor R5, diode D1, and capacitor C3 in parallel with resistor R4.

The drain-to-source path of JFET Q1 acts as a low resistance when Q1's gate is biased to zero volts. However, the resistance of the path approaches infinity when Q1's gate is biased to a negative pinchoff value of a few volts. When dial potentiometer R6 is suitably adjusted, the circuit oscillates and generates very little distortion in its output with a peak-to-peak value of X volts.

If the output tries to rise above a set value (X), the detected change automatically increases Q1's resistance value. This response reduces the operational amplifier's gain, bucking the attempted rise in output. However, if the output tries to fall below the X value, an opposite response occurs—gain increases to maintain a constant output level.

To organize the Fig. 10 circuit, connect its output to an oscilloscope and adjust trimmer R7 to the lowest setting that will give stable oscillation without visible distortion of the waveform over the 1.5 kHz to 15 kHz band. If the Wien bridge components are well matched, THD could be less than 0.1%. The output signal amplitude depends on the pinchoff characteristics of the 2N3819 JFET, a value that is typically between 2.5 and 7 volts, peak-to-peak.

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Alternatively, the pinchoff level can be preset to 8 volts, peak-to-peak, by connecting a 10-kilohm potentiometer across the operational amplifier's output and supplying resistor R5 from its wiper.

The AGC system's charge/discharge time constants are controlled by R5 and C3 and R4 and C3. The R4-C3 time constant must be long with respect to that of the generated waveform cycle for low distortion. If the oscillator is to generate signals with frequencies as low as 15 Hz, the value of capacitor C3 must be increased to 2.2 μF. However, if capacitor C3 is removed, the circuit will have a simple distortion-generated gain control.

Wide-frequency oscillator

The frequency ranges of the oscillator circuits in Figs. 6 to 10 can be changed with different values of capacitors C1 and C2. For example, increasing those values by a factor of 10 reduces the frequency by a factor of 10. Those circuits can become wideband multidecade oscillators by installing switches for selecting alternative decade capacitor values.

The maximum useful operating frequency for this kind of circuit is restricted by the slew rate limitations of the operational amplifier. The useful frequency limit for the low-cost 741 operational amplifier is 20 kHz. That limit is raised to 80 kHz with a 741S, 120 kHz with a National Semiconductor LF355, and 250 kHz for a National Semiconductor LF356.

If you build a variable-frequency Wien-bridge oscillator, be sure that the two tracks of the frequency-control potentiometer are well matched if you want low-distortion and stable-amplitude performance. In multidecade oscillators, the values of the Wien-bridge capacitors should be as closely matched as is practical on all ranges. If these capacitors are not well matched, it might be necessary to install an AGC GAIN or DISTORTION switch for each range.

Figure 11 is the schematic for a variable-frequency Wien-bridge oscillator whose output covers the 15-Hz to 15-kHz frequency band in three switched decade ranges. The circuit includes thermistor stabilization, as previously described, and it generates an output with low-distortion. The frequency output of the oscillator can be switched with rotary switch S1 in three bands: 15 Hz to 150 Hz, 150 Hz to 1.5kHz, and 1.5 kHz to 15 kHz. The amplitude of the output signal can be changed with switch S2.

The frequency limit of this oscillator can be increased to 150 kHz by replacing the 741S operational amplifier with a National Semiconductor LF356 operational amplifier and adding a pair of switch-selected 0.001μF range capacitors.

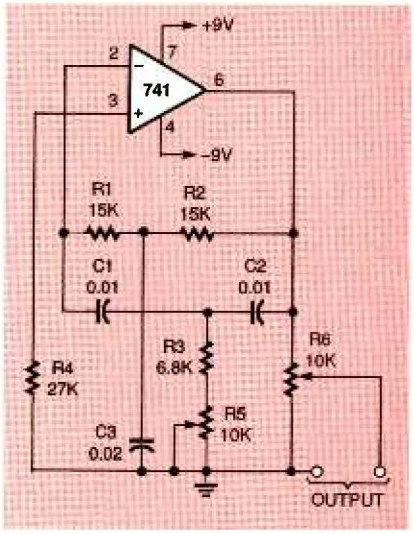

FIG. 13—THIS TWIN-T OSCILLATOR generates a 1-kHz output.

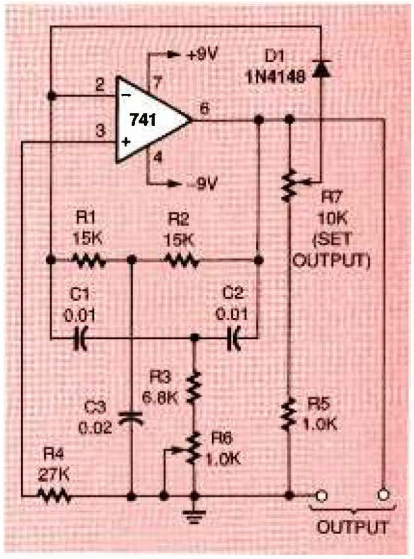

FIG. 14—A TWIN-T OSCILLATOR with diode regulation.

Figure 12 is the schematic for JFET-regulated version of the circuit in Fig. 10, modified to form an economical sine/squarewave generator. It covers the 15 Hz to 150 kHz frequency range with four settings of switch S1. Sinewave potentiometer R14 permits the sinewave's peak -to-peak output level to be preset to 8 volts. The squarewave generator section consists of common-emitter amplifier Q2 and Schmitt trigger IC2. The base of transistor Q2 is driven by the sinewave output of IC1 through R9, and Q2's emitter is biased to about −600 millivolts through diode D2 and resistor R11.

As a consequence, transistor Q2 is driven on or off whenever the sinewave swings more than a few millivolts above or below the zero-volt level. Transistor Q2 then generates a symmetrical squarewave output, and IC2 reduces the rise and fall times to less than 100 nanoseconds. The final squarewave output is available from R16. Switch S2 is the output multiplier. To conserve battery power, the squarewave generator can be switched off with switch S3-b and S3-d when the circuit is not in use.

Twin-T oscillators

The twin-T oscillator is another popular RC network-based sinewave oscillator that is useful in fixed-frequency applications. It is made by connecting a twin-T network between the output and input of an inverting operational amplifier, as shown in Fig. 13. The twin-T network consists of resistors R1 and R2 shunted by capacitor C3, and capacitors C1 and C2 shunted by resistor R3 in series with potentiometer R5.

These components form a balanced network because they are in the ratios R1 = R2 = 2(R3 + R5), and C1 = C2 = C3/2. They give a zero output at a center frequency, f of $1/2\pi \times R1 \times C1$, and a finite output at all other frequencies. If

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the Twin-T is imperfectly balanced, it gives a feeble output at its center frequency, and its output phase depends on the direction of the imbalance. In other words, if the imbalance is caused by low values of R3 + R5, the output phase is inverted with respect to the input.

The twin-T network in Fig. 13 can be adjusted by R5 so that a small phase-inverted output at a center frequency of 1 kHz can be produced. Consequently, overall phase inversion takes place around the feedback loop, and the circuit oscillates at 1 kHz. Potentiometer R5 can be adjusted so that oscillation is barely sustained. Under this condition, sinewave amplitude is limited to about 5 volts RMS by the onset of operational amplifier clipping. The output has less than 1% THD.

Figure 14 is a schematic for a simple twin-T oscillator that will have lower output distortion. Diode D1 provides distortion-generated automatic gain control. To organize this circuit, set the wiper of potentiometer R7 to the output of the operational amplifier, and adjust R6 so that oscillation is just sustained. A sinewave output of about 500 millivolts, peak-to-peak, will be produced. Ω

JACOB'S LADDER

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to those found on the schematic Fig. 1. The cores and bobbins for this transformer are from Philips (Ferroxcube) Components, Saugerties, NY). The cores are No. E187 made from 3E2A ferrite material. The plastic molded bobbins are Part No. E187PCB1-8. These parts are available from the source given in the Parts List.

Transformer T1: Wind the first 30 turns trifilar (three wires in parallel) from No. 30 AWG magnet wire and the remaining 30 turns as single wire turns. Solder the ends of the windings to the pins, insert the E-core, and tape the assembly together securely.

Transformer T2: The core of transformer is No. 4162S from Samhwa USA, Chatsworth CA, with matching seven-segment bobbin, cup and primary bobbin. These parts are also available from the source given in the Parts List.

Start winding the secondary bobbin by securing the magnet wire to a pin insulated on the bobbin end and wind between 300 and 400 turns of No. 37 AWG magnetic wire on each of seven segments. Snap the cup in place and solder the output leads. Fill the cup with epoxy or RTV silicone when you are satisfied that the transformer has been wound correctly.

Wind eight turns of No. 30 twisted wires on the primary bobbin and tape the windings in place. Form the air gap of the primary section with 0.005-inch thick Milar tape and form the air gap for the secondary section with 0.010-inch thick Milar tape. Tape or clamp the two sections together with a heavy rubber band. Ω

VIDEO NEWS

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Digital Camcorders Here

If you have a couple or three thousand dollars to spend on really top-notch video reproduction, you now can buy a digital camcorder using the standard DV (digital video) format from either Sony or Toshiba, with JVC waiting in the wings. In this column we've carried a lot of information about that DVC format (now called DV). The available camcorders produce breathtaking pictures and are ideal for professional or "prosumer" videographers.

Panasonic's model has three CCD pickups, while Sony has two models, one with three pickups and one with a single CCD. The Sony model has a digital interface and utilizes an optional feature of the DV system—a cassette with a built-in chip that stores data on tape specifications and records the date of recording and provides easy access to any scene. EN

IR LOGIC PROBE

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prepare the cable ends in the same manner as before. Solder the leads of the cable to the circuit board as shown in Fig. 2. Attach a 9-volt battery to the connector and turn on the power. The unit can be tested with an infrared remote control or an infrared LED and current-limiting resistor connected to the output of a pulse or function generator. (The IR LED can be coupled to the probe's tip with a length of ¼-inch heat-shrink tubing for test purposes.)

The tricolor LED should glow red; if not check D1 and the battery or its polarity. Point the IR LED at the probe's tip and make sure both LED indicators are functioning. If there is no indication, check the photodiode's polarity, IC1, and its associated components. If the tricolor LED does not flash amber, check IC2 and its associated components. Connect an oscilloscope to J1, and verify that a waveform is present.

Once the circuit has been checked out, join both halves of the enclosure. Be sure that the battery wires do not tangle around the LED indicators. A piece of foam rubber cut to fit the bottom of the battery compartment will keep the battery from rattling around in the case.

Using the probe

If light from windows and incandescent lamps interferes with the probe's operation, either remove the source of interference or move the work area. Ambient room light should not create problems, especially if its source is florescent fixtures.

The probe's plastic light pipe is most sensitive at the screwdriver-shaped tip. The light reflects within the walls of the light pipe (as in fiber optic cable), conducting the light to the photodiode. The probe will indicate if high-frequency pulsed IR LEDs are working, but the photodiode will integrate the pulses to a steady-state level. Ω

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